Remote sensing based ecosystem state assessment in the Sandveld Region, South Africa

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Abstract

We present a remote sensing based approach for assessing ecosystem state or intactness to inform land use management and conservation planning. Using segmented multispectral medium resolution satellite imagery, parameters related to the image objects' spectral brightness and heterogeneity, and compactness are used to derive a scoring system of 0 to 10 for the ecosystem intactness, with 0 being completely degraded and 10 being pristine. Linked to the remote sensing approach we suggest a field validation approach that focuses on 10 ecosystem-relevant visually assessed parameters which, when combined, produce a score out of 10 as well. The approach was tested in the South African Sandveld region using a SPOT 5 image from 2009 and a Landsat 7 ETM+ image from 2011. Field assessments took place in 2011. Both image data sets returned consistent results suggesting an inter-sensor transferability of the approach. Inconsistencies between satellite and field scores occurred mainly on sites where crops were currently being grown and on fields where various stages of succession were underway, following abandonment. Masking out of those sites which are of little interest from an ecosystem state perspective would improve overall accuracies. For regions with vegetation types that differ significantly in cover and structure, a stratified approach is suggested to optimise the results per vegetation type. Outputs suggest that the approach with its standardised and robust results and its repeatability provides a suitable tool for long term monitoring of large regions with a degree of detail sufficiently high to allow for fine scale planning.

Keywords: Ecosystem intactness index, ecosystem intactness field scoring system, remote sensing, image segmentation, South Africa.

Highlights

- South Africa's spectacular ecosystem and floral diversity requires effective monitoring tools to ensure its retention
- A remote sensing based ecosystem state indicator is presented
- The results can be linked to a pragmatic field assessment approach
- Results suggest inter-sensor transferability between SPOT 5 and Landsat ETM data

1 Introduction

South Africa is the third most species diverse country in the world (DEAT, 2005). With an area of 1,219,912 km^2 (about the size of Germany and France), within its borders one finds two of the world's six Floral Kingdoms, the Cape Floral Kingdom and the Palaeotropical Kingdom, with over 20,627 plant taxa (of a total of 66,142 taxa in Africa) (Cape Nature, 2007). South Africa's Western Cape Province is particularly species rich, encompassing six of the country's nine biomes and 166 of the 437 national vegetation types occurring here (Mucina & Rutherford, 2006). A number of species and communities are threatened and endangered, and the expansion of agriculture is a major conservation issue in that region. The development of rapid assessment tools, which can accurately assess and re-evaluate land cover change, ecosystem intactness and biodiversity loss are required for the rapid and accurate monitoring of these natural assets.

Biodiversity has been shown to be linked to ecosystem intactness (Ludwig et al., 2004). Therefore assessment of ecosystem intactness can deliver information on biodiversity. Ecosystem assessment in South Africa is particularly challenging when compared to European countries. The vast size of the country, the high level of diversity of ecosystems and biomes, the rapid rate at which environmental change is taking place and the high dependency on natural resources of the population, all present unique challenges to resource managers and policy makers. For example, the Western Cape Province State of Biodiversity report from 2007 (Cape Nature, 2007) requests regular monitoring of the following: Habitat transformation due to cultivation, over-grazing, mining, urban expansion and human settlements; amount of natural vegetation lost relative to national biodiversity targets, and in areas previously identified as important for biodiversity conservation; amount of natural vegetation degraded by over-grazing and invaded by alien vegetation.

Several biodiversity assessment and monitoring approaches have been presented already (e.g. Wessels et al., 2000; Dahlberg, 2000; Nagendra, 2001; Ferrier, 2002; Oindo & Skidmore, 2002; Turner et al., 2003; Smyth & James, 2004; Scholes & Biggs, 2005; Duro et al., 2007; Strand et al., 2007; Wiens et al., 2009). However, given the described differences in landscape characteristics and conservation targets, methods that have been designed for countries with limited landscape heterogeneity and extent (e.g. as presented by Bunce et al., 2008) might not necessarily meet the requirements of 'large' countries and landscapes such as South Africa and many other African countries. Sophisticated methods, while being technically feasible in 'large' countries may be too demanding with regard to the detail of information required for being rolled out efficiently over large areas. On the other hand, methods developed on a continental scale, (e.g. Fjeldsa et al., 1996) do not provide enough spatial detail necessary for local or regional planning. Other shortcomings of these approaches have also been illustrated, e.g. by Rouget et al. (2006), and thus form part of the motivation for the present research.

We present an alternative remote sensing based approach and field assessment technique for assessing natural vegetation intactness. The approach does not depend on land cover or vegetation maps as input, which frequently are not available (in sufficient detail or accuracy) in many third world countries. The approach relies primarily on medium resolution multispectral satellite imagery SPOT 5 and Landsat TM, and requires a modest amount of field work. Field assessment methods were adapted from Esler et al. (2006). The use of medium resolution multispectral satellite imagery such as SPOT 5 and Landsat TM allows for the assessment of large regions and provides sufficiently detailed spatial information to facilitate local planning. Furthermore, as the approach assesses intactness on a per-pixel-base, it allows for the assessment of intactness gradients within single land use units (Higgins et al., 1999; Jeltsch et al., 1997).

There are numerous examples of earth observation data being used for ecosystem and biodiversity assessments (e.g. Fuller et al., 1998; Griffiths et al., 2000; Nagendra 2001; Turner et al., 2003; Scholes & Biggs, 2005; Aplin, 2005; Pereira & Cooper, 2006; Muchoney, 2008). The approach presented here differs in that its standardisation allows for semiautomated repetition and comparability of the results when applied to a time series of images. Detected differences can be used for ‘hot-spot’ detection of areas where critical changes have occurred. Technically, the derived index is based on spectral as well as structural and textural land cover features, which makes it more robust than approaches solely based on spectral signals. The results of assessments undertaken around Elandsbay in South Africa’s Sandveld region in the Western Cape Province are presented and discussed, and should be seen as a base for further development of the method in collaboration with environmental and conservation managers and practitioners.

2 Materials and Methods

2.1 Study area

For this study a 100x100 km area in the Sandveld region of the South African Western Cape Province was chosen. The region is characterised by a semi-arid Mediterranean climate. Mean annual precipitation is between 150-250mm, increasing from the coast towards the east. The geology is dominated by Sandstone, forming the Cederberg Mountains in the eastern part of the region while descending towards undulating hills along the coast (Figure 1). The soils, derived from the eroded sandstone are overly sandy or loamy sandy, hence the name of the region.

The Sandveld’s richness in biodiversity depends on the maintenance of intact Fynbos (Cape Floristic Kingdom) and Succulent Karoo (Palaeotropic Kingdom; Mucina & Rutherford, 2006) vegetation. These ecosystems are dominated by shrubby, partly evergreen vegetation, and the significant topographical and climatic variations here contribute to the general diversity.

The area is intensely cultivated. Potatoes (*Solanum tuberosum*) grown under circular irrigation pivots, Red bush or Rooibos tea (*Aspalathus linearis*) and wheat (*Triticum aestivum*) fields planted between rows of relictual shrub vegetation that provides protection from the wind, dominate the region. Permanently irrigated vineyards and citrus orchards can be found along the river valleys (Van den Berg et al., 2008). Rooibos farmers rotate crops and allow fields to lie fallow for years as root fungi become problematic under long term Rooibos cultivation. Cultivation irrigation practices increase the salt content of soils, thus also leading to the periodic abandonment of these areas as well. The abandonment of fields leads to further transformation of surrounding natural vegetation resulting in a rapid and devastating destruction of natural ecosystems (CSIR, 2012).

********* insert Figure 1 here ********************

2.2 Field data based validation system

While the major aim of the presented work was on developing a fast remote sensing based approach for the rapid assessment of the ecosystem state of large areas, we also saw the necessity to provide a fast and efficient approach for the field validation of the remote sensing derived results. Therefore a visual ecosystem intactness assessment system was developed, adopting and modifying methods formerly applied for the assessment of rangeland ecosystems of the South African Karoo (Esler et al., 2006), and in Australia (Ludwig et al., 2004).

A set of 10 yes-no questions and their associated weightings were derived (Table 1). These questions relate to indicators of ecosystem condition and state, such as transformation, grazing impacts, soil condition, infiltration, vegetation structure and age, and were visually assessed in the field by the authors. According to the respective answers, a score of zero or one was given, the 1 for the respective positive answer with respect to ecosystem intactness. This results in a potential maximum score of 10 for pristine landscapes while lower values indicate a degree of damage or degradation of the ecosystem.

****************** insert Table 1 here ***************************

The scoring system was applied at 61 GPS-referenced points which were visited during a 4 day field trip in August 2011 within the 30 x 40 km Sandveld region around Elandsbay. The points were randomly selected in homogenous landscape units (as visible on the available SPOT 5 image) of at least 100 x 100m size, which were easily accessible from the road, but avoiding areas clearly influenced by the road or proximity to fences. In addition to these questions, photos and general information on vegetation, soil and general life form composition at the respective sites were also captured. Points were sampled in pristine fynbos shrublands, fynbos used as rangeland, degraded fynbos and dunes, as well as active and fallow croplands and wetlands. GPS co-ordinates were converted into geo-located point shape files, with the score information attached to these. These scores were then related to the remote sensing derived indices as described below.

2.3 Satellite data

2.3.1 General premises

For the generation of a remote sensing based intactness index, some general premises on the display of pristine, intact vegetation and degraded or transformed vegetation in satellite imagery have to be made.

Spectral premise: For many natural landscapes, intact vegetation usually shows a higher biomass and ground coverage than the same vegetation affected by degradation or disturbance (Kerr & Ostrovsky, 2003; Turner et al., 2003). Therefore, the percentage of non-vegetated bare soil per area increases with increasing degradation. On multispectral satellite imagery, bare soil usually has a higher reflectance / albedo than vegetation, therefore, bare areas appear brighter than vegetated areas (compare Figure 2). However, the authors are aware that this assumption is not necessarily true if the degradation consists of an increasing degree of invasive alien vegetative cover, or for standing crops and within-community species turnover, e.g. towards unpalatable species in the case of overgrazing. Also, some pristine vegetation types do naturally have less vegetation cover than others (e.g. dunes; this special case is dealt with in the discussion section.) In order to compensate for the cases where this general spectral premise does not count, we use additional premises to include structural and textural characteristics of a vegetation unit, both of which are sensitive to various forms of land degradation.

Structural premise: Anthropogenic landscapes have a high degree of linear geometry. Given that crops are cultivated in rectangular or circular shapes they are easily identified in medium resolution satellite imagery. In addition areas used for livestock grazing are usually fenced into more or less rectangular units. Service and access roads along the fences usually clearly separate them on the satellite images. Natural areas are usually oriented along natural topographic features. These are usually irregular and non-geometric in shape, such as curvi-linear riverbeds, coastlines or dunes and mountain sites with different inclination and orientation angles. When segregating the satellite image into homogenous objects image metrics such as the ‘compactness’ can be used to express these criteria, assuming natural landscape elements being less compact than anthropogenic units.

Textural premise: Natural landscapes usually have a mixed age, species and life form structure which have different spectral reflectance properties (different shades of green). Varying canopy heights, especially in woody vegetation types furthermore create light and shadow effects, altogether creating a characteristic heterogeneous pattern of spectral reflectance (Nagendra, 2001, Rocchini et al., 2010). In contrast, planted crops are usually mono-cultures of the same age and have a homogenous canopy structure and reflectance. In landscapes used as rangeland, selective removal (or increase) of certain plant life forms or reduced success in rejuvenation can also lead to a reduction of vegetation structure and thus spectral heterogeneity, indicating a reduced ecosystem intactness. Therefore, our textural premise is that an increase in textural complexity is an indicator for increasing ecosystem intactness, and vice versa (Duro et al., 2007). However, exceptions can be found for some naturally homogenous vegetation types such as reeds. In such cases, the spectral and structural premises described above are required for the accurate assessment of such areas.

As an example, in accordance with this so called spectral variation hypothesis (Nagendra, 2001), a cultivated or intensely used rangeland would show up on a satellite image as a rectangular or round structure, with a comparably homogeneous canopy structure that might be brighter (less dense vegetation) or greener in the case of a standing crop than the pristine surrounding landscape. These premises have been translated into a remote sensing based algorithm which is implemented as a ruleset within an object oriented image processing software package (eCognition Version 7.0).

Image pre-processing

For testing the algorithm, two independent earth observation data sets were employed, a subset of the SPOT 5 scenes 117/414-415 (9 February 2009; Figure 2) as well as a subset of a Landsat 7 ETM+ scene (path-row 175-82) captured on the 15th of August 2011 (Figure 3). The Landsat acquisition date coincides with the field campaign conducted in August 2011.

The SPOT 5 image was acquired from the South African National Space Agency as a Level 3 product, ortho-rectification and a radiometric correction for sensor effects already applied. The only pre-processing required for the SPOT image was the mosaicking of the two scenes and the creation of a subset for the 30 x40 km area around Elandsbay region visited during the field trip (Figure 1).

********* insert Figure 2 here ********************

********* insert Figure 3 here ********************

The Landsat 7 image was sourced as a Level 1T product from the United States Geological Survey (USGS) GloVis website (http://glovis.usgs.gov/). This product is orthorectified but not radiometrically corrected and thus an atmospheric correction was conducted. As the region is overly flat and no significant image distortions through relief effects occurred, the ATCOR-2 software has been used for this purpose which is based on the AFRL MODTRAN code (Richter, 2011). This step was conducted to allow for quantitative comparisons between Landsat images for future time series studies in the area. Subsequently the multispectral Landsat image was pan-sharpened to improve the resolution from 30m to 15m using a principal component algorithm and cubic convolution resampling. The resolution enhancement was required as initial tests using the 30m resolution data indicated that relevant linear landscape features were not being resolved at that pixel size.

Diagonal black lines found on the Landsat image are data gaps produced by the scan line correction error (http://landsat.usgs.gov/products_slcoffbackground.php) and have not been corrected. This results in blank diagonal stripes in the image and in the results. Water bodies were masked out in both scenes.

2.3.2 Generation of image derivates

The images were initially segmented using eCognition software, with weighting 100% on colour and 0% on shape; scale parameter 50 for the SPOT image and scale parameter 30 for the pan-sharpened Landsat. Segmentation parameters were selected following iterative segmentation experiments, where the authors varied the input parameters and assessed the resulting segmentation. These parameters have proven suitable for application in savanna environments as well.

For the resulting polygons (generated by the segmentation), the mean brightness as a measure for the fraction of soil signal and thus an inverse measure of vegetation density was computed (=spectral premise; Figure 4a). Secondly, the mean standard deviation of the near infrared band (NIR) was computed (Figure4b). Vegetation reflectance in the NIR range of the electromagnetic spectrum provides a good base for differentiation between species, ages and canopy shadow effects and thus can be used as a proxy for vegetation texture (Jensen, 2006; Nagendra, 2001; =textural premise).

The compactness of the segments was also computed (=structural premise; Figure 4c) as a way of measuring the land cover structure. Compactness was calculated as follows

$$\text{Compactness} = 4\pi * \text{Area} / (\text{Perimeter})^2$$

with 0 being the minimum for highly fractured landscape structures and 1 being the maximum value for perfectly circular structures (Darwish et al. 2003). The shape of image objects could thus be classified based on the compactness parameter with near circular image objects more likely to be anthropogenic (values closer to 1) while lower values are more likely to be natural vegetation.

********* insert Figure 4 here ********************

The three output layers were rasterised, and water bodies were masked out. Subsequently, the brightness layer's original data range was re-scaled to value ranges from 0-to-1, in order to optimally stretch the contrast (information contained in the image). This means, the histogram of the distribution of grey values was analysed, and the lowest 0.5% and the highest 0.5% of the data were omitted, assuming them being noise. Then a linear function was applied to the remaining data transforming the lowest original value to being 0 and the highest original value to being 1 and all the remaining data being distributed between them. The NIR standard deviation of the core 99% of the data was re-scaled to a data range of 0-to-2 using a linear function. The NIR standard deviation was stretched to 0 to 2, to give this parameter more weight than the brightness, as initial trials with the individual parameters showed a very strong correlation to the majority of the field data. The original compactness data range lies between 0 and 1, so no stretch was applied.

According to the three premises stated above, an increase in NIR band standard deviation is seen as being proportional to ecosystem intactness. In contrast, an increase in polygon compactness and brightness is related to a decrease in ecosystem intactness (Figure 5). Therefore for the generation of the index, the re-scaled compactness and brightness data were inverted, using the function [1 – pixel value].

********* insert Figure 5 here ********************

2.3.3 Generation of index

The intactness index was then calculated by summing the results from the converted brightness, NIR standard deviation and compactness layers for each pixel, with a possible total score between 0 and 4, the latter for “pristine” areas. The summed values were then re-scaled (linear stretch) to a data range between 0 and 10 to facilitate comparisons between the field scoring range and the earth observation index, with 10 being the optimal and 0 being the worst possible ecosystem/biodiversity state.

2.3.4 Validation of remote sensing results

For the validation of the results, the scores for the field sites were compared with the respective remote sensing derived scores. While all 61 field points could be used for the SPOT 5 image, for the Landsat image only 43 points could be used as 18 of the field points fell into the blank SLC error lines, which was unforeseeable, as the Landsat image was captured during the time of our field trip and only became available a couple of weeks later, preventing us to select test sites outside of the Landsat gaps.

In order to assess the inter-sensor transferability of the approach, a set of 226 additional random points was generated. The ecosystem intactness scores of both images for these points were compared and analysed. The selection of random points excluded water bodies and the no-data lines in the Landsat image.

3 Results

3.1 Validation using field data

The results for the intactness indices derived from the 2009 SPOT 5 image and the 2011 Landsat image are displayed in Figure 6 and Figure 7.

********* insert Figure 6 here ********************

********* insert Figure 7 here ********************

For the accuracy assessment using the field data, we subtracted the respective satellite-derived score from the field score for the respective validation point in the field. A list of the results for all sites and both sensors is given in the Appendix. We assigned a “correct” score to all points where the difference between field score and remote sensing score was $\leq \pm 2$, for instance if the field score was 5 and the remote sensing score was between 3 and 7, it scored as correct. Incorrect scores are shaded grey in the Appendix. We allowed this relatively large degree of freedom as the primary purpose was to test whether the remote sensing approach could pick up general patterns comparably to those derived from the field data.

Using this approach, the 2009 SPOT derived index returned an accuracy of 62.3%, with 38 of the 61 points having a score difference of less than 3 (comprising the range between minus 2 and plus 2 thus ignoring the algebraic sign) between the field and SPOT 5 score (Table 2).

***************insert Table 2 here ************************

The 2011 Landsat derived index returned an accuracy of 76.7%, with 33 of the total 43 sites showing a difference of ± 2 or less between the field and the Landsat score (Table 3).

***************insert Table 3 here ************************

From the 61 sites, 25 sites were identified correctly by both sensors. From the 38 points correctly classified by the SPOT data, 25 were also correctly classified by Landsat, one was incorrectly classified by Landsat only, and for the remaining 12 sites no Landsat data were available. A total of nine sites were classified incorrectly by both sensors, an additional 14 sites were misclassified by SPOT (see Appendix).

In Table 2 and Table 3 the validation results per sensor are aggregated into three land use types, namely untransformed natural vegetation according to question 1 in Table 1, indicated as “n” in the Appendix, sites transformed into agricultural field, indicated as “y” in the Appendix. As a subclass of “transformed” for the analysis we define ‘old fields’ “(y)” as fields which appear to have been abandoned for a number of years, but remain in a state of early recovery, and which are very different to the natural vegetation state.

In the SPOT image, 79.5% of the untransformed areas have been classified correctly and 25% and 40% of the transformed and old fields, respectively (Table 2). In the Landsat image, 80.8% of the untransformed sites have been classified correctly and 77.8% and 62.5% of the transformed and old fields, respectively (Table 3).

3.2 Validation using random points

The pivot table in Table 4 summarises the results of this experiment. The column "count of events" summarises the number of score events for the points. For instance, the "event" for a random point scoring a 1 for Landsat and a 2 for SPOT occurred once. The event for a point scoring a 4 for Landsat and a 3 for SPOT occurred twice, and so on. The last column of the table indicates the difference between the Landsat and SPOT scores.

***************insert Table 4 here *************************

In the result, from the total of 226 points analysed, 86 points (38.1 %) scored exactly the same ecosystem intactness value in both images (difference between Landsat and SPOT = 0) and for 186 points (82.3%) the score was the same or with a difference of +/- 1 between the images (shaded grey in Table 4).

4 Discussion

4.1 Achieved accuracies: vegetation type issues

The overall accuracies achieved for both the SPOT and Landsat images were only moderately satisfactory. The remote sensing scores were frequently higher than the field scores, as indicated by negative difference values (see Appendix). In most cases these overestimations related to transformed areas and old fields. The accuracy scores for untransformed natural areas were generally higher.

In highly dynamic intensely used agricultural landscapes such as the Sandveld, a high degree of land cover change, i.e. in terms of standing crop versus ploughed fields is to be expected, when comparing field data and satellite imagery from different seasons. Fallow fields and old fields frequently scored too high with the emergent herbaceous layer creating structural heterogeneity, which led to an increase in the NIR standard deviation. In the remote sensing scoring system, this incorrectly implies a higher degree of ecosystem intactness, while the field scores were low, given the observed disturbance in vegetation structure and composition (which the satellite did not pick up). Some non-irrigated crop fields were also classified incorrectly. These were generally atypical sites such as narrow strips between a road and a riverbed. The image segmentation process lead to the creation of elongated or partly fragmented shapes with lower polygon compactness values and these received higher remote sensing scores.

When the results were discussed with biodiversity managers and practitioners, the general consensus was that the errors relating to transformed areas were negligible and should be ignored, given their low value for conservation purposes in the examined environment. This perception has to be seen in the South African context. Because in Europe, according to the CORINE land cover data, most of the landscapes are transformed already, they cannot be threatened further in this respect. Therefore the focus of European policy is rather on protecting the biodiversity and ecosystems that depend on agricultural or semi-natural land (Donald et al., 2002, Reif et al., 2008). In contrast, according to the National Land Cover 2000 (Van den Berg et al. 2008), agriculture (including planted grasslands but excluding natural rangelands) and forest plantations make about 12% of the total (terrestrial) area in South Africa (total non-natural area including urban and mines: ca 14%) ranking the priority of agricultural areas comparably low for conservation purposes However, given the rapid population growth, natural habitat transformation for cultivation and urban expansion is perceived as being one of the 3 most important issues in landscape conservation in South Africa (Cape Nature, 2007).

Other instances of incorrect classification occurred in vegetation types with a naturally lower vegetation density such as open or sparsely vegetated dune fields. This resulted in high image brightness values which incorrectly reduced the remote sensing score. The overly high brightness values with little contrast in the 8 bit coded SPOT and Landsat images furthermore cannot produce high NIR standard deviation values. This further reduced the remote sensing score for these particular sites.

In contrast, areas invaded by alien vegetation such as Eucalypt or Australian Acacia tree species are characterised frequently by high patchiness with local high vegetation density which leads to high NIR standard deviation values and/or low brightness values, thus leading to inappropriate high remote sensing scores. Unexpectedly, wetlands covered with *Phragmites* reeds were scored correctly as intact natural habitats, despite this vegetation having a crop-like nature with an assumed homogenous vegetation structure and high vegetation density. The high NIR standard deviation values for these areas however suggest that when examined from a vertical perspective (from the satellite) the reeds seem to be much less homogenous than when viewed from the horizontal.

4.2 Inter-sensor transferability

The comparison of the index results from the Landsat and SPOT images using the random points, being largely in the same range (for 186 points or 82.3% of the 226 points the score was ≤ ± 1), indicate the sensor-independency of the approach. The selected points included transformed areas, old fields and urban areas. Excluding those points is likely to increase the accuracies further.

4.3 Impact of seasonality

The analysis of the results of the random points and the comparison with the field data also highlights another, somewhat surprising result: Seasonal effects do not seem to cause significant scoring differences for natural vegetation on the SPOT image which was captured in February 2009, at the height of the dry season, and the Landsat image and the field campaign which are dated August 2011, when vegetation growth is at its peak. It was anticipated that the dry season SPOT image with somewhat more open vegetation would have produced lower remote sensing scores (due to higher brightness values) when compared to the peak vegetation field and Landsat scores. However, the largely comparable scores for natural areas in both images indicate this was not the case. The normalisation procedure (described in section 2.3.3) which is optimising for the actual brightness data range of the respective image may have compensated for those effects. However, until we are able to further test the robustness of our approach to seasonal influences, for future applications we would recommend using images from the same season for field and satellite observation where possible.

4.4 Technical issues of applied method

We were concerned that the use of the Landsat 7 images with the scan line errors may affect the polygon compactness measure. There was however no evidence to suggest this was the case, though we are aware that the number of validation points might be too low for a proper analysis of such effects.

The relatively large degree of freedom we allowed for the validation of the results (the ± 2 range of allowed deviance between field and remote sensing score) is debatable. The approach still requires development in terms of both the definition of the optimal set of questions in the field scoring as well as in the optimal usage of the spectral, structural and textural premises.

At this stage our three premises and the data stretch functions built on these are simple and assume linear relationships. Future research is needed to validate the nature of these relationships and perhaps a different weighing of the three factors may further enhance accuracies. We also expect those functions to differ between different vegetation types (Nagendra, 2001).

4.5 Comparison with other research

Oldeland et al. (2010) examined the relationship between spectral variation (our textural premise) and ecosystem intactness (in terms of biodiversity), using hyperspectral imagery, species richness and abundance-based Shannon Index respectively. They identified relationships between the spectral variability and the Shannon Index. These findings resonate with our results despite their relationships having relatively low R^2 values. However, Oldeland et al. (2010) also found that data outliers are the main reason for the weak statistical relationships identified.

While the presented approach will benefit from further development, the results show potential and benefit when compared with other approaches that attempt fine scale remote sensing assessment of environments. The presented approach was developed within the context of the EBONE EU FP-7 project, as a complementary approach to the biodiversity monitoring tools developed for Europe within that project (Bunce et al., 2008). However, while the results showed that the suggested assessment is usable in the South African context (Olsvig-Whittaker et al., 2011) the willingness of the practitioners and stakeholders to adopt the scheme was relatively low. A reason for this might be that the focus of the EBONE method, developed for a European context, appropriately emphasises on the assessment of biodiversity in agricultural and transformed landscapes, being where the remaining species diversity is now found. In contrast, more than 80% of South Africa’s landscapes are still considered natural and about 12% of land has been transformed to agriculture. These areas do not receive much conservation, and the key challenge in South Africa lies in the assessment and monitoring of the vast natural landscapes. Therefore, if no satisfactory system for spatial and temporal extrapolation of the information derived using Bunce et al.’s (2008) is available the information cannot be used at the regional scale where relevant land-use decisions are made.

4.6 Suggestions for taking this research forward

As observed with the naturally sparse dune vegetation in the study region, very bright areas are only occupying a small range of the available grey value range of the 8 bit coded SPOT and Landsat input images. When displayed, these areas have only little contrast, which also leads to low NIR standard deviation values. The re-scaling/normalisation increases the contrast/data range somewhat, but in the context of the entire image, the variation of the derived intactness within the dune system is probably not displayed realistically.

The most feasible solution to overcome this shortcoming is to treat different vegetation types within one region separately, e.g. by stratifying the landscape using existing vegetation or land cover maps or an (un-)supervised classification of the image. The normalisation of the brightness, compactness and NIR standard deviation can then be optimised per vegetation type, creating an appropriate intactness index per vegetation type. Also using existing land cover data for the purpose of eliminating other landscape features which negatively influence the value range such as dark water bodies, urban areas or areas covered by clouds (very bright) or cloud shadows (very dark) is expected to improve results. Our work demonstrated that masking out the transformed areas immediately increased the classification accuracy.

Another further option for improving the spectral contrast relates to the selection modern satellite sensors, such as WorldView-2 and RapidEye, whose data are 16-bit coded, resulting a value range of 65 536 values, instead of Landsat’s 8-bit 256 value range. These data are currently costly, but have better spatial resolution, too. Whether or not a fine spatial resolution is required depends on the local situation and needs to be decided by the applicant (Hengl, 2006). Rocchini et al. (2010) found several studies where ecological remote sensing assessments performed actually better using Landsat-type imagery with more spectral bands than using IKONOS imagery with higher spatial resolution but less spectral bands.

When comparing the scores of the Landsat and the SPOT images for the single sites, the differences between the scores per site are constantly low (class differences for majority of points between +1 and -1; compare inter-sensor transferability test above), i.e. in both sensors the sites achieved similar intactness index results. This highlights that the approach is applicable across sensors and that it is relatively insensitive to radiometric image conditions (with or without radiometric correction). However, such a “mixed” approach with its inherent difficulties of calibrating the derived results is less than ideal.

For ecosystem intactness monitoring in an operational management support environment, the use of radiometrically or at least image-to-image corrected data using e.g. ATCOR software or empirical algorithms such as Dark Object Subtraction (Chavez, 1996; Song et al., 2001) from only one sensor is usually a better option. The use in a monitoring environment, i.e. for the analysis of a time series of images for one area would require defining the parameters (brightness, compactness etc.), the functions for the normalisation and the scaling thereof on one reference data set, and applying these rules to the images of the other dates, without any modifications. In this way, excluding seasonal differences between the images, the detected variances between the ecosystem intactness indices between the different images should reflect true changes on the ground.

Another field which obviously still requires some research is the set of questions which we used for the field validation. In the South African context, the transformed areas turned out to be of no interest for conservation purposes and pulled down the overall accuracy of the remote sensing derived index. For the remote sensing scoring, we recommend to mask transformed areas out and ignore them. Analogous for the field validation, several of the current questions might not really be applicable for agricultural fields, such as “signs of lifestock” or “senescence”. Following the current set of questions consequently, agricultural fields would score positively on those questions as there are no lifestock and no signs of old vegetation to be found, which does not really make sense. Therefore if the selection of transformed areas cannot be avoided in the field validation, we suggest a “knock-out system” for crops in the application of the questions: if the first question (area transformed?) is answered positively, assign an intactness value of zero and ignore all the following questions.

Furthermore, the current set of questions was adopted from a land management guide for a dwarf shrub environment. Should the method be applied to other environments, we recommend an expert familiar with the respective vegetation types and land use practise critically revises the set of questions.

Also the number of questions to be used might be adapted, depending on the respective circumstances, knowledge, skills and time available. We do however recommend that the value range of the possible field scores should match the value range of remote sensing index scores. While a reduction of the set of questions might make the field assessment faster, we would like to point out that also the value of the intactness index will unfortunately decrease. The ideal range of questions and possible index scores needs to be evaluated for each situation.

5 Conclusions

This study presents an indirect approach for the measure of ecosystem intactness (Duro et al., 2007; Turner et al., 2003). We have coupled a remote sensing approach with a relatively simple field scoring system based on ten ecologically relevant questions. The results allude to the robustness of the remote sensing approach with regards to inter-sensor transferability and seasonal independence.

Reasonable ecosystem intactness results can be produced with this approach. These can provide as baseline for a standardised monitoring tool for conservation and land use management. The particular strength of the approach lies in its ability to indicate gradients of ecosystem intactness in space (within land use units) and over time as well as in its independence of detailed land cover or vegetation maps, which usually do not exist in many developing countries. Existence of such data, however, might be beneficial to support the presented approach. Further research and application in other environments and habitats would enhance both the approach and our understanding of the relationship between image derivates (brightness, compactness etc.) and ecosystem intactness.

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References

Aplin, P., 2005. Remote sensing: Ecology, Progress in Physical Geography 29 (1), 104–113.

Bunce, R.G.H., Metzger, M.J., Jongman, H.G., Brandt, J., de Blust, G., Elena-Rossello, R., Groom, G.B., Halada, L., Hofer, G., Howard, D.C., Kovář, P., Mücher, C.A., Padoa-Schioppa, E., Paelinx, D., Palo, A., Perez-Soba, M., Ramos, I.L., Roche, P., Skånes, H., Wrbka, T., 2008. A standardized procedure for surveillance and monitoring European habitats and provision of spatial data. Landscape Ecology 23, 11–25.

Cape Nature, 2007. Cape Nature Scientific Services: Western Cape Province State of Biodiversity 2007, 175 pages (p.136).

Chavez, P.S., 1996. Image-based atmospheric corrections – Revisited and improved. Photogrammetric Engineering & Remote Sensing, 62(9) 1025-1036.

CSIR, 2012). FINAL REPORT, Water Use Surveillance and Ecological Economic Modeling of Agro-Ecosystems in the Sandveld region, Western Cape. (Ed. KG Kennedy). 182pp.

Dahlberg, A.C., 2000. Interpretations of environmental change and diversity: A critical approach to indications of degradation - The case of Kalakamate, northeast Botswana. Land Degradation & Development 11 (6), 549-562.

Darwish, A., Leukert, K., Reinhardt, W., 2003. Image Segmentation for the Purpose of Object-based Classification. IGARSS 2003, IEEE, Toulouse, France.

DEAT, 2005. South Africa's National Biodiversity Strategy and Action Plan. Department of Environmental Affairs and Tourism, Pretoria, South Africa.

Donald, P.F., Pisano, G., Rayment, M.D., Pain, D.J., 2002. The Common Agricultural Policy, EU enlargement and the conservation of Europe's farmland birds. Agric. Ecosyst. Environ. 89, 167-182.

Duro, D.C., Coops, N.C., Wulder, M.A., Han, T., 2007. Development of a large area biodiversity monitoring system driven by remote sensing. Progress in Physical Geography 31 (3), 235–260.

Esler, K.J., Milton S.J., Dean, R.J., 2006. Karoo Veld – Ecology and Management. Briza, Pretoria, South Africa, 214 pages.

Ferrier, S., 2002. Mapping spatial pattern in biodiversity for regional conservation planning: Where to from here? Syst. Biol. 51 (2), 331-363.

Fjeldsa, J., Ehrlich, D., Lambin, E., Prins, E., 1996. Are biodiversity 'hotspots' correlated with current ecoclimatic stability? A pilot study using the NOAA-AVHRR remote sensing data. Biodiversity and Conservation 3(3), 401-422.

Fuller, R.M., Groomb, G.B., Mugishac, S., Ipulet, P., Pomeroye, D., Katendef, A., Bailey, R., Ogutu-Ohwayoh, R., 1998. The integration of field survey and remote sensing for biodiversity assessment: a case study in the tropical forests and wetlands of Sango Bay, Uganda. Biological Conservation 86, 379-391.

Griffiths, G.H., Lee, J., Eversham, B.C., 2000. Landscape pattern and species richness; regional scale analysis from remote sensing. International Journal of Remote Sensing, 21 (13&14), 2685–2704.

Hengl, T., 2006. Finding the right pixel size. Computers & Geosciences 32, 1283–1298.

Higgins, S.I., Shackleton, C.M., Robinson, E.R., 1999. Changes in woody community structure and composition under contrasting landuse systems in a semi-arid savanna, South Africa. Journal of Biogeography, 26, 619–627.

Jeltsch, F., Milton, S., Dean, W.R.J., van Rooyen, N., 1997. Simulated pattern formation around artificial waterholes in the semi-arid Kalahari. Journal of Vegetation Science 8: 177-188, 1997.

Jensen, J.R., 2006. Remote Sensing of the Environment: An Earth Resource Perspective. (2nd Edition), Upper Saddle River, NJ: Prentice Hall, 592 pages.

Kerr, J.T. and Ostrovsky, M., 2003. From space to species: ecological applications for remote sensing. Trends Ecol. Evol. 18, 299–305.

Ludwig, A.J., Tongway, J.D., Bastin, N.G., James, D.C., 2004. Monitoring ecological indicators of rangeland functional integrity and their relation to biodiversity at local to regional scales. Austral Ecology 29 (1), 108-120.

Muchoney, D.M., 2008. Earth observations for terrestrial biodiversity and ecosystems. Remote Sensing of Environment 112. 1909–1911.

Mucina, L. & Rutherford, M.C., 2006. The Vegetation of South Africa, Lesotho and Swaziland. Strelitzia 19. Pretoria: South African National Biodiversity Institute, 808 pages.

Nagendra, H., 2001. Using remote sensing to assess biodiversity. International Journal of Remote Sensing, 22 (12), 2377–2400.

Oindo, B.O., Skidmore, A.K., 2002. Interannual variability of NDVI and species richness in Kenya. International Journal of Remote Sensing 23 (2), 285-298.

Oldeland, J., Wesuls, D., Rocchini, D., Schmidt, M., Jürgens, N., 2010. Does using species abundance data improve estimates of species diversity from remotely sensed spectral heterogeneity? Ecological Indicators 10, 390–396.

Olsvig-Whittaker, L., Frankenberg, E., Magal, Y., Shkedy, Y., Amir, S., Walczak, M., Luck-Vogel, M., Jobse, D., de Gelder, A., Blank, L., Carmel, Y., Levin, N., Harari-Kremer, R., Blankman, D., Boeken, B., 2011. EBONE in Mediterranean and desert sites in Israel, with notes on South Africa. Alterra Report 2260, December 2011. Alterra, part of Wageningen UR, Wageningen. 56 pp.

Pereira, H. M. and Cooper, H. D., 2006. Towards the global monitoring of biodiversity change. TRENDS in Ecology and Evolution 21 (3), 123-129.

Reif, J., Storch, D., Volínek, P., Kpastný, K., Bejbek, V., 2008. Bird-habitat association predict population trends in central European forest and farmland birds. Biodiversity Conservation 17, 3307–3319.

Richter, R., 2011. Atmospheric / Topographic Correction for Satellite Imagery. ATCOR-2/3 User Guide, Version 8.0.2, August 2011. DLR report DLR-IB 565-02/11, Wessling, Germany.

Rocchini, D., Balkenhol, N., Carter, G.A., Foody, G., Gillespie, T.W., He, K., Kark, S., Levin, N., Lucas, K., Luoto, M., Nagendra, H., Oldeland, J., Ricotta, C., Southworth, J., Neteler, M., 2010. Remotely sensed spectral heterogeneity as a proxy of species diversity: Recent advances and open challenges. Ecological Informatics 5, 318–329.

Rouget, M., Cowling, M.R., Vlok, J., Thompson, M., Balmford, A., 2006. Getting the biodiversity intactness index right: the importance of habitat degradation data. Global Change Biology 12 (11), 2032-2036.

Scholes, R.J., Biggs, R., 2005. A biodiversity intactness index. Nature 434, 45-49.

Smyth, K.A., James, D.C., 2004. Characteristics of Australia's rangelands and key design issues for monitoring biodiversity. Austral Ecology 29 (1), 3-15.

Strand, H., Höft, R., Strittholt, J., Miles, L., Horning, N., Fosnight, E., Turner, W., 2007. Sourcebook on Remote Sensing and Biodiversity Indicators. Secretariat of the Convention on Biological Diversity, Montreal, Technical Series No. 32, 203 pages.

Song, C, Woodcock, C.E., Seto, K.C., Pax Lenney, M., Macomber, S.A., 2001. Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects? Remote Sensing of Environment, 75, 230–244.

Turner, W., Spector, S., Gardiner, N., Fladeland, M., Sterling, E., Steininger, M., 2003. Remote sensing for biodiversity science and conservation, TRENDS in Ecology and Evolution 18 (6), 306-314.

Van den Berg, E.C., Plarre, C., Van den Berg, H.M. & Thompson, M.W., 2008. The South African National Land Cover 2000. Agricultural Research Council-Institute for Soil, Climate and Water, Pretoria. ARC Report No. GW/A/2008/86).

Wessels, K.J., Reyers, B., Van Jaarsveld, A.S., 2000. Incorporating land cover information into regional biodiversity assessments in South Africa. Animal Conservation 3, 67-79.

Wiens, J., Sutter, R., Anderson, M., Blanchard, J., Barnett, A., Aguilar-Amuchastegui, N., Avery, C., Laine, S., 2009. Selecting and conserving lands for biodiversity: The role of remote sensing. Remote Sensing of Environment 113, 1370-1381.

Appendix

List of the validation points with the respective field, SPOT and Landsat scores as well as a short site description. Incorrect remote sensing scores are shaded in grey.

No	Site Name	Field score	2009 SPOT5 score	2011 Landsat score	Difference FIELD-SPOT5	Difference FIELD-Landsat	Transformed acc. to question 1 in Table 1?	Site description
1	H2	5	7	6	-2	-1	n	*Galenia** dominated degraded bush
2	V2	7	9	7	-2	0	n	natural bush, degraded
3	_1a	5	7	7	-2	-2	n	degraded grazed patch at slope
4	N	6	8	8	-2	-2	n	*Galenia** dominated, overgrazed shrubs
5	U1	7	8	7	-1	0	n	"quarry" dune slope
6	4	7	7	6	0	1	n	mobile dune field edge
7	G2	8	8	7	0	1	n	better wetland
8	1north	8	8	8	0	0	n	lightly grazed natural fynbos
9	A1	7	7	8	0	-1	n	cattle-grazed natural fynbos
10	A2	9	9	8	0	1	n	sparsely grazed almost intact fynbos
11	H1	9	9	8	0	1	n	almost intact fynbos
12	_4b	10	10	8	0	2	n	*Phragmites* reeds
13	L2	8	8	9	0	-1	n	wetland
14	K1	9	8	7	1	2	n	natural shrub fringe
15	_1b	9	8	8	1	1	n	grazed bush, better condition
16	_5a	7	6	8	1	-1	n	heavily overgrazed bush
17	X	6	4	4	2	2	n	alien *Acacia*** dunes
18	3east	9	7	8	2	1	n	natural low sedge-dominated slope
19	3west	9	7	8	2	1	n	natural low sedge-dominated slope
20	D	7	8	n.d.	-1	n.d.	n	bush, burnt before 2009
21	C	8	8	n.d.	0	n.d.	n	grazed bush
22	L1	8	8	n.d.	0	n.d.	n	crumbled slope
23	_6a	9	9	n.d.	0	n.d.	n	degraded bush
24	1south	8	7	n.d.	1	n.d.	n	lightly grazed natural fynbos
25	O2	10	9	n.d.	1	n.d.	n	pristine fynbos
26	Q1	10	9	n.d.	1	n.d.	n	pristine fynbos
27	Q2	10	9	n.d.	1	n.d.	n	pristine fynbos
28	_3a	9	8	n.d.	1	n.d.	n	degraded bush
29	R2	10	8	n.d.	2	n.d.	n	*Restia-Nilantia* mix
30	_3b	6	8	n.d.	-2	n.d.	n	degraded bush with *Nilantia*
31	O1	5	7	n.d.	-2	n.d.	y	ploughed melon field
32	_5b	4	3	5	1	-1	y	wheat-legume field
33	M2	6	7	6	-1	0	y	strip farming windbreaks
34	G1	6	7	7	-1	-1	(y)	old ploughed riverbed
35	B3	8	7	6	1	2	(y)	windbreak strip in crop field
36	B1	5	7	5	-2	0	(y)	old field
37	E	4	6	5	-2	-1	(y)	*Galenia** dominated, old ploughed field

38	U2	10	9	7	1	**3**	n	intact coastal dune
39	J2	4	7	6	**-3**	-2	n	*Galenia** field
40	W	6	9	7	**-3**	-1	n	overgrazed dune patch
41	S2	4	8	n.d.	**-4**	n.d.	n	eroded slope
42	R1	10	7	n.d.	**3**	n.d.	n	*Restia-Nilantia* mix
43	F	3	7	5	**-4**	-2	y	fallow Pivot
44	M1	4	7	6	**-3**	-2	y	strip farming wheat
45	M3	4	7	6	**-3**	-2	y	continuous wheat field
46	_2a	4	7	5	**-3**	-1	y	wheat-legume field
47	V1	4	7	6	**-3**	-2	y	wheat field at cliff slope
48	S1	3	7	n.d.	**-4**	n.d.	y	ploughed land
49	_7	4	7	n.d.	**-3**	n.d.	y	wheat field
50	K2	3	6	5	**-3**	-2	(y)	old land
51	T	3	7	n.d.	**-4**	n.d.	(y)	fallow lands
52	J1	4	7	n.d.	**-3**	n.d.	(y)	old field (pivot?)
53	2south	1	5	5	**-4**	**-4**	n	bare with sparse *Eucalypt*** trees
54	2north	1	5	5	**-4**	**-4**	n	bare with sparse *Eucalypt*** trees
55	Y1	10	7	6	**3**	**4**	n	intact low dune field
56	Y2	10	7	6	**3**	**4**	n	intact low dune field
57	_6b	3	9	9	**-6**	**-6**	y	ploughed field
58	_4a	4	8	8	**-4**	**-4**	y	wheat field
59	B2	3	6	6	**-3**	**-3**	(y)	abandoned wheat strip
60	A3	2	7	6	**-5**	**-4**	(y)	heavily degraded, grazed, old field?
61	I	3	8	7	**-5**	**-4**	(y)	old field
		Total number of sites:			**61**	43		
		n.d.: no data						*: degradation indicator
								*: alien species in South Africa

Captions for figures

Figure 1: Overview of the 30x40 km test site in the Sandveld region in the Western Cape Province, South Africa. Centre coordinate of the site: 32°19’08”S 18°28’17”E. Yellow ∆: position of the 61 field validation sites.

Figure 2: Subset of the site around Elandsbay. SPOT 5 image from February 2009, north-oriented. Pixel size 20m. Band combination RGB: 3-4-2 (NIR-SWIR-red). Displayed image extent ca 22x16 km. Subset centre coordinate ca. 32°20’17”S, 18°25’05”E. Structures of intense agricultural use are clearly visible, such as circular irrigation pivots (potatoes, A), strip farming with linear wind break hedge rows interspersed (wheat or red bush tea, B) and life stock farming of varying intensity in the remaining fynbos shrub vegetation (C). Irregular white patches: natural open dune fields (D). The red fringes around the water body are reeds (E).

Figure 3: Subset of the pan-sharpened Landsat 7 ETM scene175-82 from August 2011 for the same area as in Figure 2. Pixel size 15 m. Band combination RGB: 4-5-3 (NIR-MIR-red, comparable to the band combination chosen for the SPOT image in Figure 2). Black lines: no data due to Landsat SLC error. Differences to the 2009 SPOT image are caused by seasonality and partly different land use in the two years.

Figure 4: Derived from 2009 SPOT image after image segmentation of same are as in figures above: 4a: brightness; 4b: NIR standard deviation; 4c: image object compactness. Colour range from dark grey to white: low to high brightness, NIR standard deviation and compactness values, respectively.

Figure 5: Premised relationship between the mean segment brightness, segment compactness, NIR band standard deviation and the field-observed ecosystem intactness, respectively.

Figure 6: Ecosystem intactness index derived from the same SPOT image as in Figure 2. Values 0 to 10: index values: high values indicate high degree of ecosystem intactness.

Figure 7: Ecosystem intactness index derived from Landsat 7 image from August 2011 (Figure 3). Values 0 to 10: index values: high values indicate high degree of ecosystem intactness. Black lines: unclassified (no data due to Landsat SLC error).

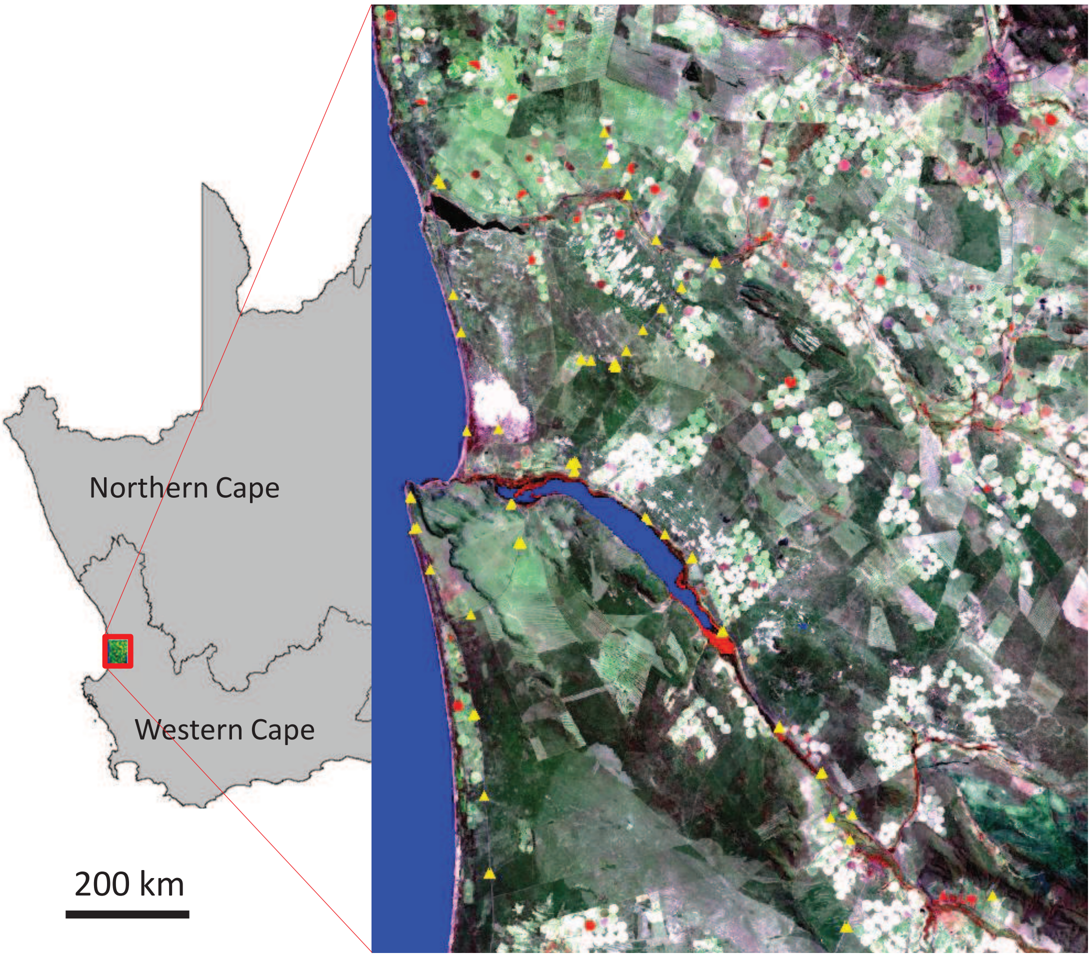

Figure 1

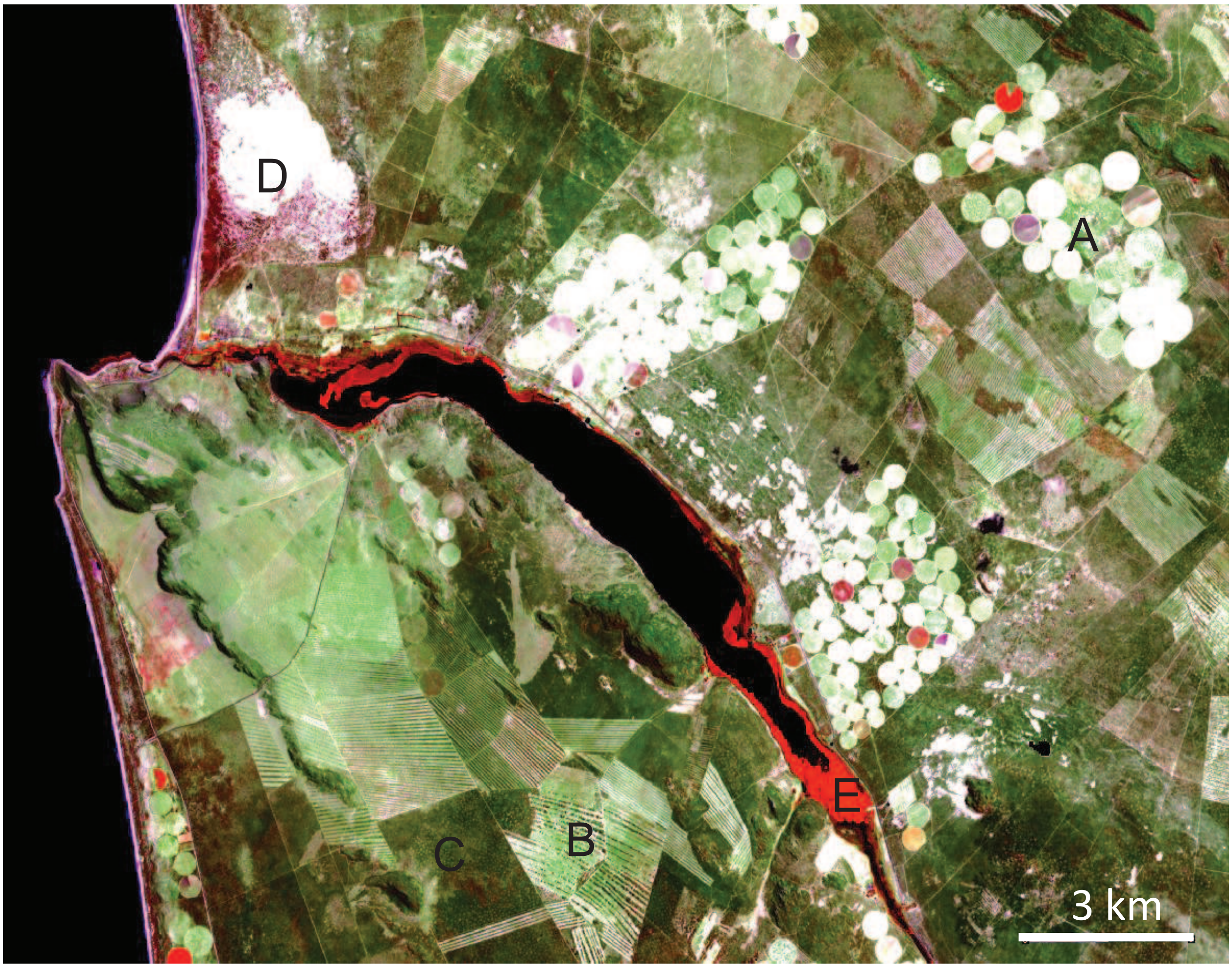

Figure 2

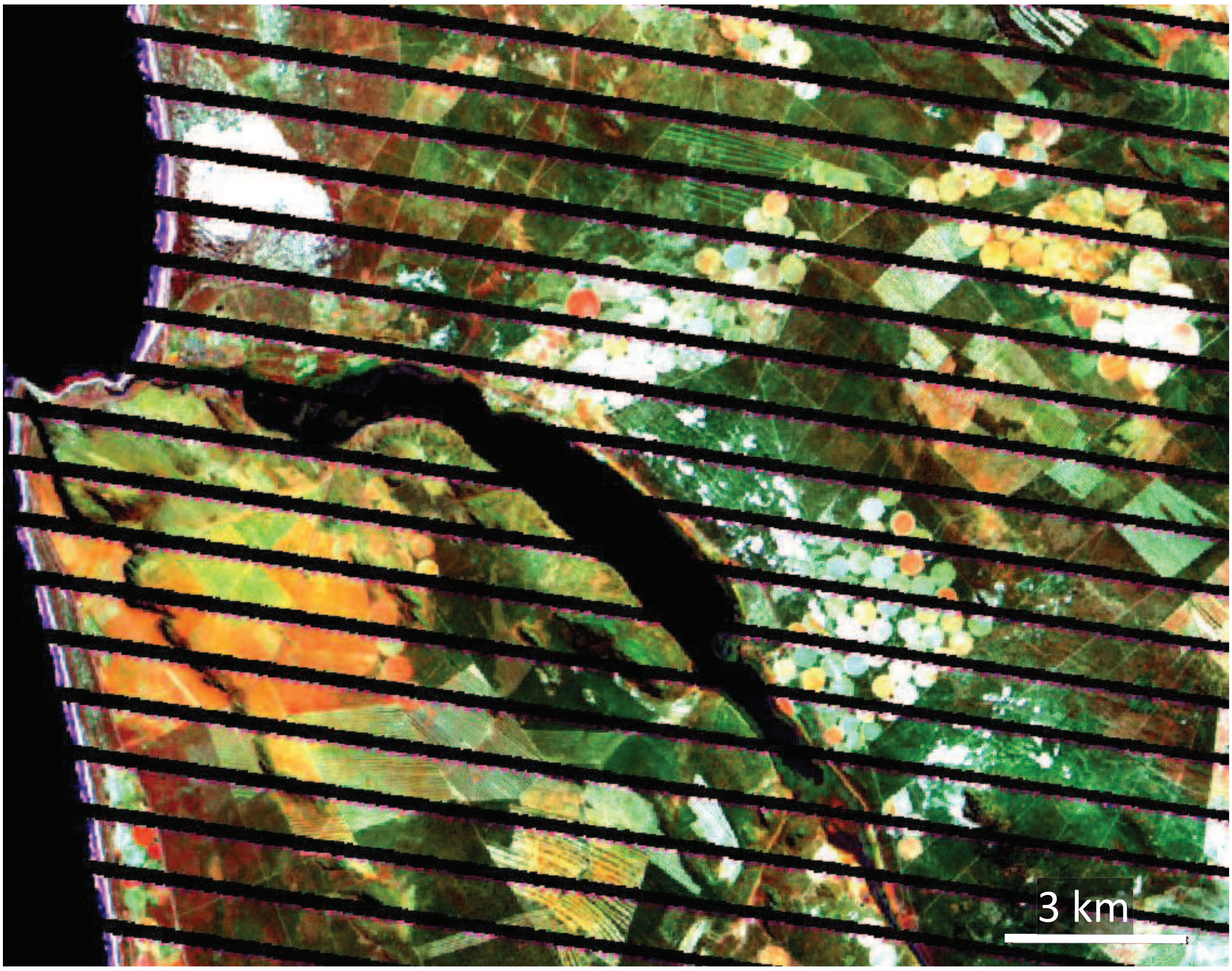

Figure 3

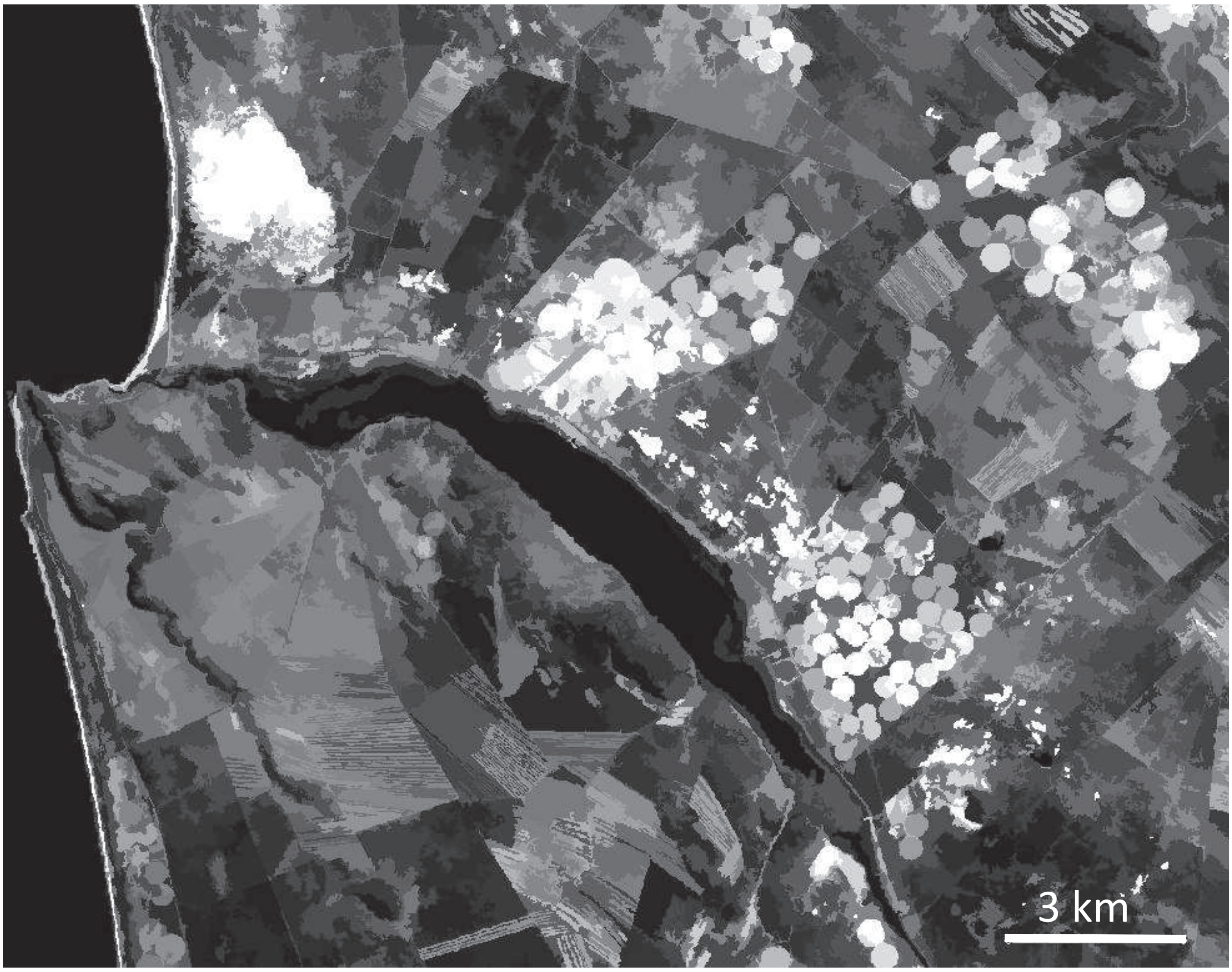

Figure 4a

Figure 4b

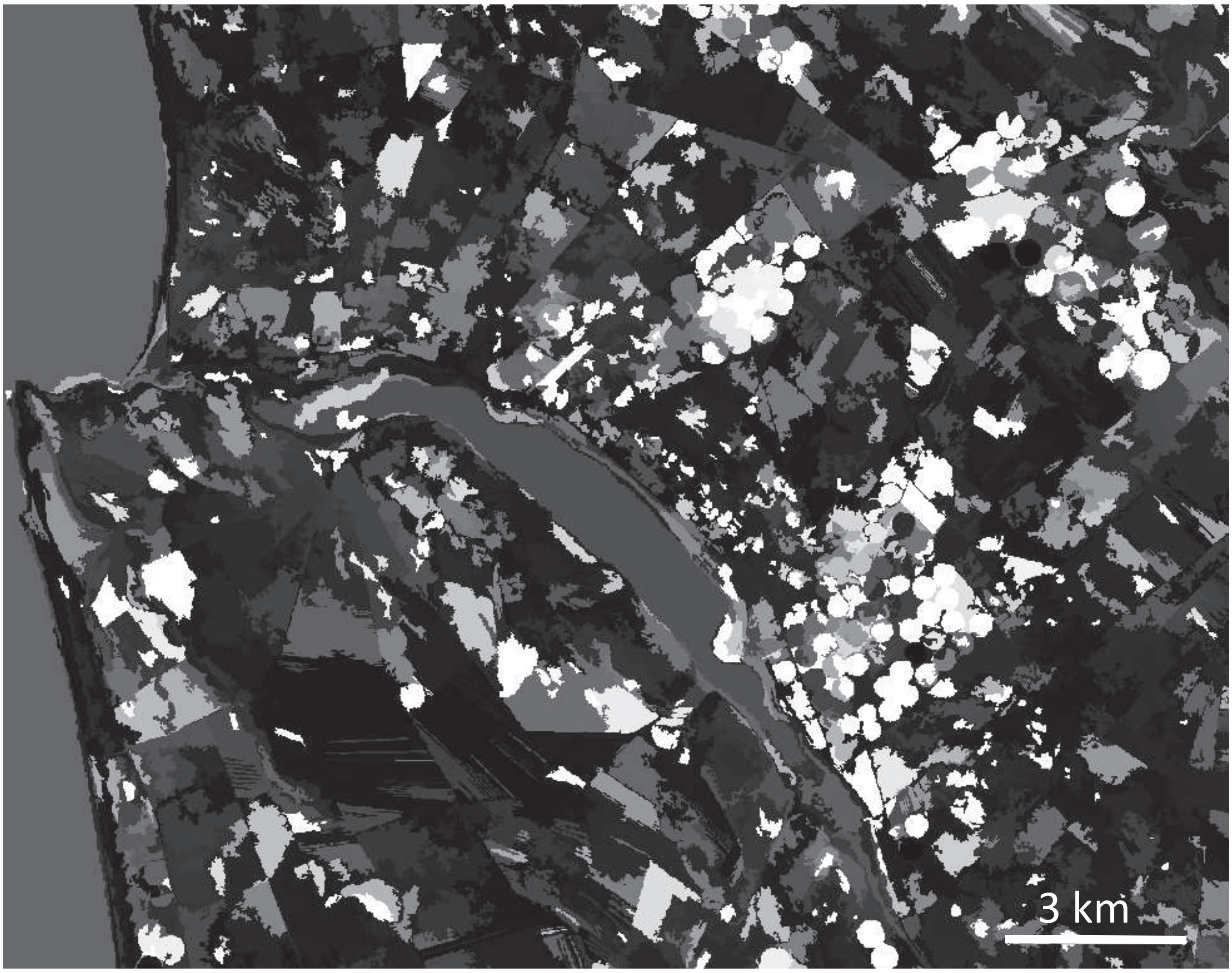

Figure 4c

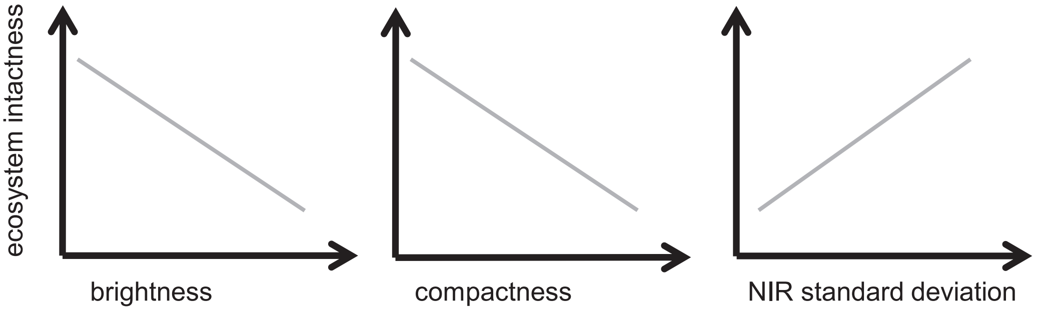
ecosystem intactness
brightness
compactness
NIR standard deviation

Figure 5

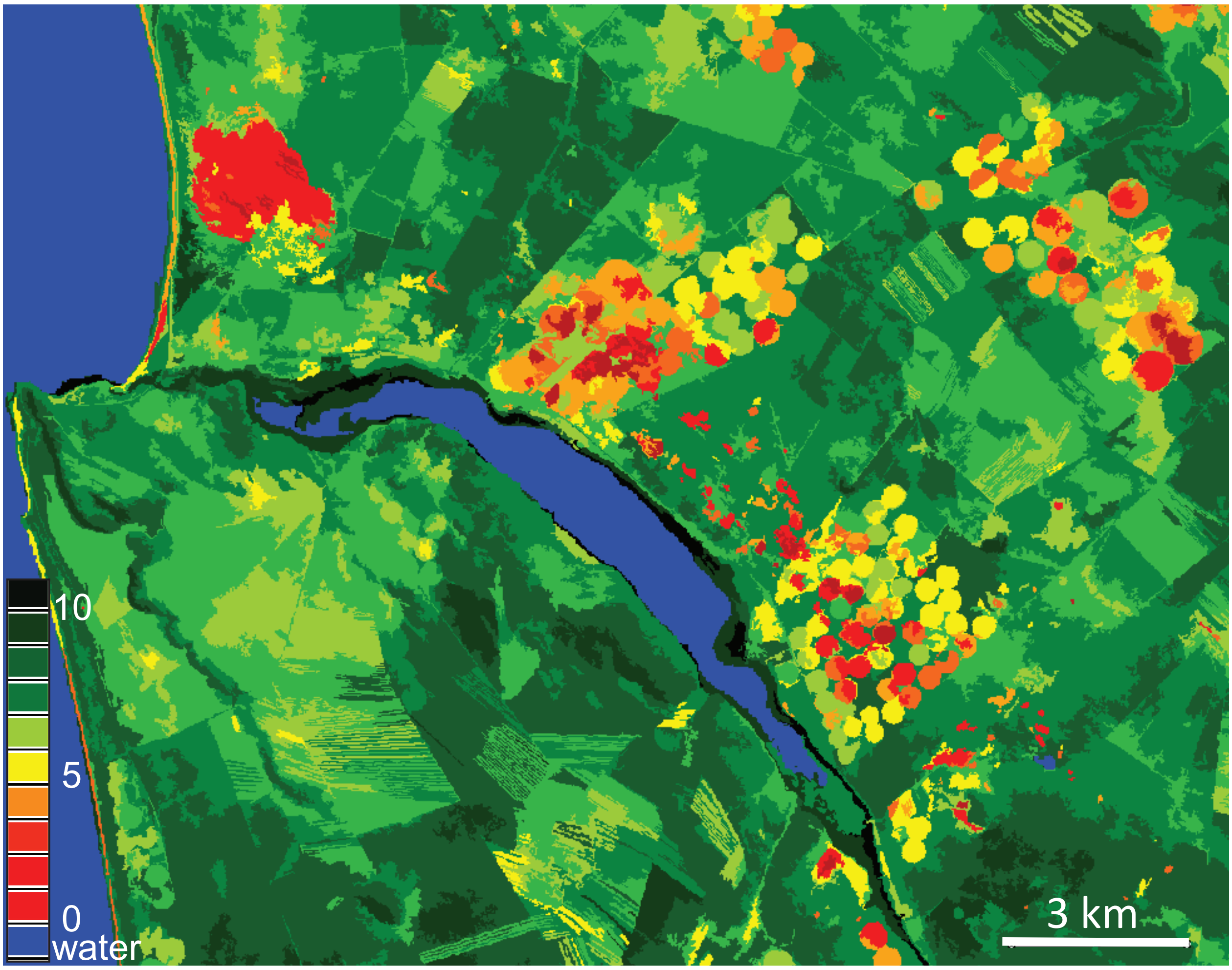

Figure 6

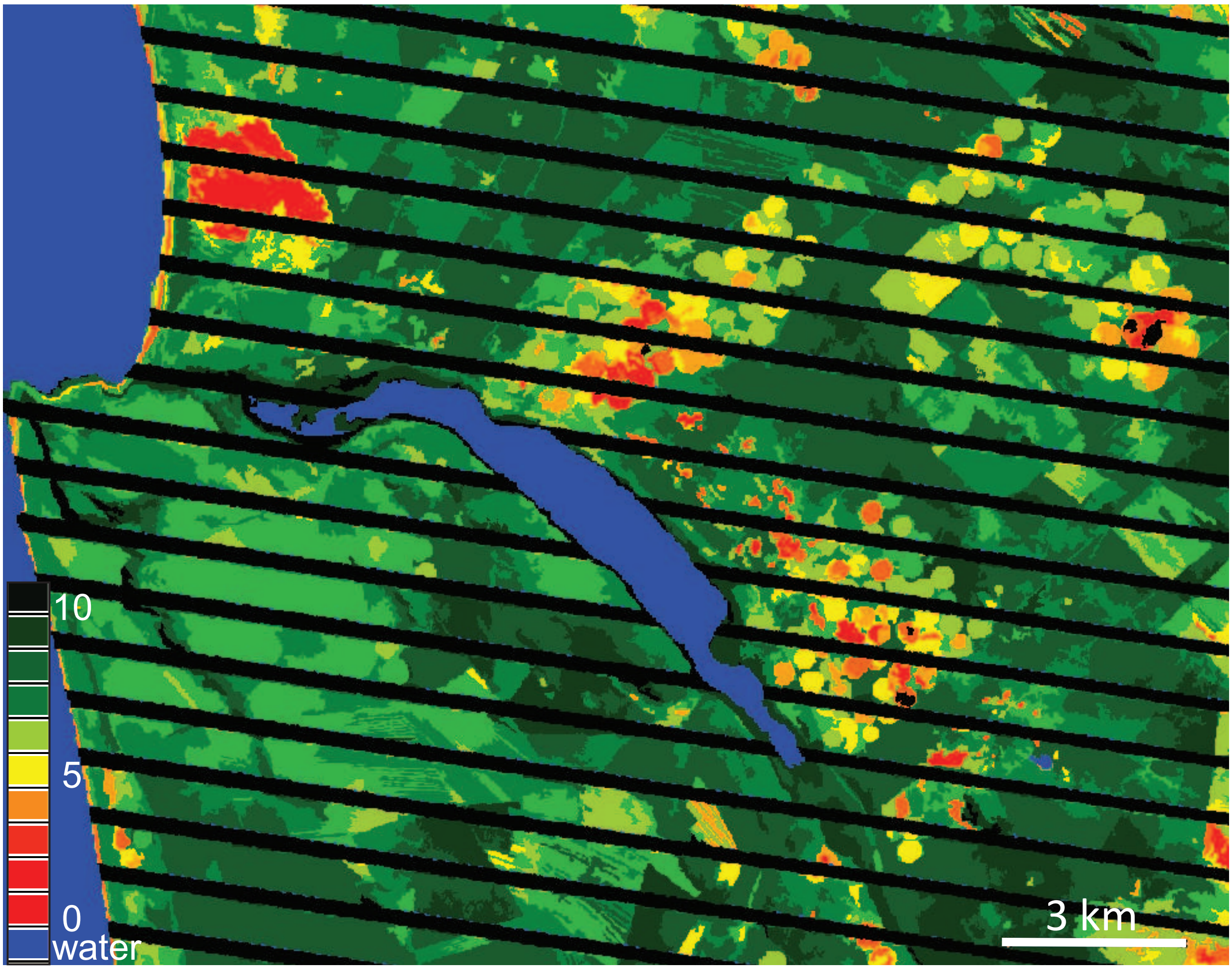

Figure 7

Table 1: Catalogue of questions applied on the field validation sites

No	Question	Explanation	If answer YES, score as	If answer is NO, score as
1	Has the area been transformed?	Is there evidence of cultivation	0	1
2	Is the area used for livestock production?	Are there signs of manure, trampling, vegetation removal	0	1
3	Are there signs of management related soil degradation?	Are bare roots, damaged soil, or soil crust evident	0	1
4	Is plant litter present?	Are soil processes being maintained in terms of organic carbon being returned to the soil	1	0
5	Does grazing intensity appear to be high?	Is there evidence of degradation of vegetation by stock?	0	1
6	Do less palatable species dominate?	Have less palatable and unpalatable species taken over demonstrating overgrazing	0	1
7	Does the variety of natural vegetation lifeforms appear to have been reduced?	Has the diversity of lifeforms been maintained	0	1
8	Is there a composition of multistorey life forms present?	Has the natural vegetation structural heterogeneity been maintained	1	0
9	Is there small scale vegetation patchiness or heterogeneity?	Natural patches of species domination across the landscape	1	0
10	Are there signs of vegetation senescence?	Increase of dead plant parts or over-aged specimen	0	1

Table 2: Summary of SPOT scores by land use type

Land use type	**correct**	**% correct**	**incorrect**	**total points per class**
untransformed	31	79.5	8	39
transformed	3	25.0	9	12
old fields	4	40.0	6	10
total	**38**	**62.3**	**23**	**61**

Table 3: Summary of Landsat scores by land use type

Landsat only	**correct**	**% correct**	**incorrect**	**total points per class**
untransformed	21	80.8	5	26
transformed	7	77.8	2	9
old fields	5	62.5	3	8
total	**33**	**76.7**	**10**	**43**

Table 4: Summary of random point test on inter-sensor comparability. Correct scores are shaded grey.

Landsat score	SPOT score	count of events	diff LS-SPOT
1	2	1	**-1**
3	5	1	-2
4	3	2	**1**
4	6	1	-2
4	7	1	-3
5	2	1	3
5	4	1	**1**
7	2	1	5
7	3	1	4
7	4	1	3
7	9	1	-2
8	5	1	3
9	6	1	3
9	10	1	**-1**
2	1	2	**1**
3	4	2	**-1**
5	8	2	-3
6	9	2	-3
7	5	2	2
4	5	3	**-1**
5	7	3	-2
6	8	3	-2
8	9	3	**-1**
5	6	4	**-1**
6	3	4	3
8	6	4	2
7	8	5	**-1**
9	9	6	**0**
6	7	8	**-1**
9	8	9	**1**
5	5	10	**0**
6	4	10	2
6	5	12	**1**
7	6	19	**1**
6	6	23	**0**
8	8	23	**0**
7	7	24	**0**
8	7	28	**1**

KML File (for GoogleMaps)

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